UCID-20348

INTENSE ELECTRON BEAMS FOR DIRECTED ENERGY WEAPONS RESEARCH

Adrian C. Smith, Jr.
and the Beam Research Program Staff

January 1985

Lawrence Livermore National Laboratory

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under Contract W-7405-Eng-48.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $; Microfiche $4.50

Page Range	Domestic Price	Page Range	Domestic Price
001-025	$ 7.00	326-350	$ 26.50
026-050	8.50	351-375	28.00
051-075	10.00	376-400	29.50
076-100	11.50	401-426	31.00
101-125	13.00	427-450	32.50
126-150	14.50	451-475	34.00
151-175	16.00	476-500	35.50
176-200	17.50	501-525	37.00
201-225	19.00	526-550	38.50
226-250	20.50	551-575	40.00
251-275	22.00	576-600	41.50
276-300	23.50	601-up[1]	
301-325	25.00		

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ABSTRACT

The following is the script for the film

"Intense Electron Beams for Directed Energy Weapons Research."

At the Lawrence Livermore National Laboratory located east of the San Francisco Bay Area, scientists and engineers in the Laboratory's Beam Research Program are studying the utility of intense beams of high energy electrons for defensive weapons.

The Program's mission is two-fold: (1) establish whether these intense particle beams can be projected through the air in a controlled manner and (2) establish whether the electron beams' concentrated energy can be efficiently converted into powerful, short wavelength laser and microwave beams.

Work performed jointly under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract W-7405-ENG-48 and for the Department of Defense under Defense Advanced Research Projects Agency ARPA Order No. 4395 Amendment No. 31, monitored by Naval Surface Weapons Center under document number N60921-84-WR-W0080.

Narrative script for Lawrence Livermore National Laboratory film No. PR15271, January 1985.

Located in a remote test site East of Livermore is the centerpiece of the Laboratory's Beam Research Program, the Advanced Test Accelerator, or "ATA." Built for the Department of Defense, ATA is the most advanced electron beam accelerator of its type in the free world.

The accelerator is a cylindrical structure three feet in diameter and 260 feet long which sits in a tunnel 24 feet underground. The surrounding earth provides shielding from the intense radiation produced by the accelerated beam.

ATA consists of two parts: an injector, which provides the electrons to be accelerated, and a linear induction electron accelerator which adds energy to the electrons. The energy to accelerate the electrons is delivered through cables connected to electrical pulse generators located at ground level.

The injector, which sits at the end of ATA, is a very high-powered, high-quality electron gun. Conceptually, it is similar to the electron gun in the picture tube of an ordinary television set. But ATA's injector is 100 billion times more powerful than a TV gun: ATA's injector delivers electron beam pulses having an energy of 2-1/2 million volts. Each pulse, which lasts only 50 billionths of a second, carries a current of 10,000 amperes.

Once it leaves the injector, the electron beam pulse enters the accelerator. Here, energy is added to the electrons in steps, using the same physical principles that govern the operation of an electric transformer.

ATA, like any linear induction accelerator, consists of many high voltage pulsed transformers linked end-to-end. As the electrons thread through the center of each transformer, an electrical pulse delivered to the transformer adds an increment of energy to the beam pulse. In ATA, 180 transformer modules impart an energy of about 50 million volts to the electron beam. Each accelerator module is powered by its own pulse generator located above the accelerator.

A recent innovation of great significance is the method used to transport the electron beam down the center of ATA. A very weak laser pulse is sent down the bore of the accelerator just ahead of the electron beam pulse. This laser pulse creates a dime-sized channel of slightly ionized gas down the entire length of the accelerator. This ionized channel guides the electron beam down the center of ATA. The energy of the laser pulse is about 50,000 times smaller than the energy of the electron beam it is guiding! This "laser-guiding" technique, invented at Livermore in 1982, eliminates the need for complex and costly magnets to focus the beam. And an electron beam guided through the accelerator by a laser can carry much more current without suffering any disruptions.

The hardware developed for ATA is rugged pulse-power/transformer technology with simple requirements on vacuum systems and mechanical alignment. And the overall efficiency of ATA is currently about 40%, with improvements in the range of 60%-75% believed possible for upgrades of the accelerator.

Despite its size and complexity, ATA was designed and automated so that the accelerator can be operated by one person. A network of computers and microprocessors continuously monitors the high power accelerator's performance and collects experimental data for later analysis.

ATA began operating in 1983. In Spring 1984, the accelerator met its design specification: 50,000,000 volt electron beam pulses carrying 10,000 amperes and lasting 50 billionths of a second were produced at the rate of one per second. All 10,000 amperes emerging from ATA are carried by a beam having about the same diameter as a pencil with an instantaneous power of 500 billion watts.

Experiments with the ATA beam will soon be conducted in a variety of carefully controlled atmospheres inside a one-foot diameter, 24-foot-long metal tank located beyond the end of the accelerator. Shortly thereafter, a large concrete shield door will be moved aside and ATA's beam pulses will be directed out of the accelerator into the open air where their free-flight propagation can be studied. These experiments will help determine how these intense beam pulses can be directed stably through the air toward remote targets.

One possible defense application of this technology is a ground-based electron beam battle station defending high-valued targets from incoming threats. Ship-based particle beam weapons for fleet defense are also being considered. These applications draw upon a well-established fact: high energy, high current electron beams can dismember thick pieces of metal in less than a millionth of a second. Since high energy electrons penetrate deeply into solid metal, it is practically impossible to prevent catastrophic damage to a target engaged by an electron beam weapon.

New directed energy weapon concepts are also being considered, combining laser beams and electron beams. An attractive feature of these concepts is that pointing and tracking can be done with the laser while the particle beam which follows it destroys the target.

At a small, experimental test facility called the High Brightness Test Stand (HBTS), pulse power technology is being developed that will vastly increase the pulse rate -- and hence the average power -- of ATA.

The HBTS accelerator is powered by specially designed magnetic elements which compress the energy of the pulses delivered to the accelerator modules.

The small accelerator sits at the bottom of a pool of water which provides shielding from the intense radiation produced by the beams.

ATA is designed to fire five times per second. But the technology being developed at the HBTS has fired at a rate of 1000 times per second. As a result, by Spring of 1985 this small accelerator will be the most powerful in the free world, producing an average electron beam power of over one megawatt -- more average beam power than the two-mile-long Stanford Linear Accelerator.

If ATA were refitted <u>today</u> with modules identical to those in use at the HBTS, it could be fired over 1000 times per second producing an electron beam with an average power of 25-35 MW -- about the same as the power required to meet the needs of a city of 25,000 people.

The advent of this high average power capability in ATA makes possible the efficient conversion of the electron beams' energy into very high average power, short wavelength laser beams. The conversion device is called the Free Electron Laser Amplifier. As its name implies, this device uses the energy available in the electron beam to <u>amplify</u> the intensity of a second beam of light or microwaves.

The operation of a Free Electron Laser Amplifier is as follows: The amplifier consists of a hollow structure called a "wiggler," an electron beam, a master signal source which provides the beam of microwaves or visible light to be amplified, and a beam dump for recovering the left-over electron beam energy. The wiggler consists of a long, hollow array of magnets in which the North-South orientation of adjacent magnets is reversed.

The electron beam and the laser beam light to be amplified both enter the wiggler together. The wiggler's magnetic field causes the electrons to undulate back and forth and the electrons begin to give off radiation -- like a radio station's antenna. But <u>this</u> antenna moves through the wiggler at nearly the speed of light. Just as an approaching train's whistle is shifted to higher frequencies by the Doppler Effect, the frequency of the wiggling electron beam's radiation is dramatically increased. Under the right conditions, this Doppler-shifted radiation synchronizes with the laser light and energy can be transferred from the electron beam to the laser beam.

As the beams proceed through the wiggler, the electron beam consequently becomes weaker while the light beam becomes more intense. When the beams reach the end of the wiggler, the electron beam is guided into a beam dump where, if need be, some of its energy can be recovered and used to produce the next electron beam pulse. The laser beam, now amplified by as much as 10,000 times or more, proceeds straight ahead.

The main reason for interest in the free electron laser is that the efficiency of this whole process can be quite high -- in the range of 20% - 30% -- due to the high quality, high-current electron beams produced by induction linacs. This is several times more efficient than is currently believed possible in conventional lasers.

Research on Free Electron Laser Amplifiers of microwaves is being pursued at Livermore in a test-bed called the Electron Laser Facility, or "ELF." A four million volt electron beam is guided from the Experimental Test Accelerator into ELF's 3-meter-long wiggler assembly. This wiggler has been designed to amplify microwaves with millimeter wavelengths.

In experiments conducted to date, ELF has amplified an initial microwave signal three-thousand-fold and has converted 6% of the electron beam energy into microwaves. This radiation is so intense (its power exceeds 80 MW) that the microwave energy breaks down the air in the laboratory in a striated pattern of sparks.

The detailed theoretical work that underlies the ELF design accurately describes the outcome of the ELF experiments. The computer models predict that ELF should eventually be able to convert as much as 40% of the electron energy to microwaves. The same computer models are being used to design a 25 meter Free Electron Laser Amplifier of infrared light to be installed in the Free Electron Laser experimental hall at ATA. Experiments are expected to begin in this facility in 1986.

A trench was dug in the hillside just beyond the end of ATA's Free Electron Laser facility. In this trench, an extended experimental hall will be constructed to provide an exit path for the intense radiation emerging from the wiggler. The length of this trench (approximately 150 meters) shows about how far we expect the beam must travel before its natural tendency to spread out dilutes its power enough that a single pulse will not vaporize or melt anything in its way.

Upgrading ATA with the technology of the HBTS would yield extremely high average power beams with energies in excess of one hundred million electron volts. Injecting this beam into a 50 meter wiggler could produce, by 1989, near-visible light at unprecedented average power levels. This would be a major step on the road to establishing feasibility of ground-based short-wavelength FELs for strategic defense applications. Conceptually, one can imagine aiming such a beam up to relay mirrors in space which direct and focus it onto the threat.

The Beam Research Program at the Lawrence Livermore National Laboratory is a highly integrated and dynamic research effort. Its experimental program, centered at the ATA, is based on the synergism between intense beams of electrons and beams of laser light.

The program is based on a reasoned pace of physics and technology accomplishments and development. The facilities and technology of this program are now poised to determine the feasibility of several advanced directed energy weapons concepts for our nation's defense.

ACS/mcs:9012v/8578v